

An Economic Analysis of Potential Rotation Crops for Maine Potato Cropping Systems

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ABSTRACT

Potato cropping systems in Maine include both continuous potatoes and short-term potato rotations with small grains. Producers recognize the benefits of increased rotations, but the economics of producing a high-valued crop such as potatoes (*Solanum tuberosum* L.) create incentives for continuous potato production. Research at the USDA-ARS research site in Newport, ME, is evaluating the agronomic and economic impacts of five crops in two-year rotations on potato production and whole-farm profitability. The rotation crops are barley (*Hordeum vulgare* L.), sweet corn (*Zea mays* L.), green bean (*Phaseolus vulgaris* L.), soybean (*Glycine max* L., Mer.), and canola (*Brassica napus* L.). Enterprise budgets for the five crops were developed. The budgets and historical prices and yields were used as inputs to a Monte Carlo simulation. The simulation was conducted to determine the impact of rotation crops on whole-farm profitability and income risk, as measured by income variability. The net incomes of the five rotation sequences were compared against continuous potatoes. Two rotation crops, sweet corn and green beans, resulted in an increase in net income relative to continuous potatoes. All of the rotation crops were found to greatly reduce income risk and chance of economic losses. In the case of green beans and sweet corn, the analysis was rerun using data from the research trials on the following potato crop yields. Depending on whether the rotation effect was negative or positive, net income either fell or rose when compared to first analysis. However, even when the rotation crop led to decreased

yields in the following potato crop, income variability and likelihood of economic loss was still superior to the continuous potato rotation. These findings provide support for including rotation crops as a method to improve potato production and sustainability, increase whole-farm profitability, and reduce income risk.

RESUMEN

Los sistemas de cultivo de papa en Maine incluyen tanto rotaciones continuas como rotaciones de períodos cortos de papa con cultivos de grano pequeño. Los productores saben de los beneficios que aportan las rotaciones, pero desde el punto de vista económico, la producción de cultivos de alto valor tal como papa (*Solanum tuberosum* L.) crean mayores incentivos en la producción continua de papa. La investigación del ME en el USDA-ARS en Newport, está evaluando los impactos agronómico y económico de cinco cultivos en rotaciones de dos años sobre la producción y las utilidades. Los cultivos de rotación son cebada (*Hordeum vulgare* L.), maíz dulce (*Zea mays* L.), frijol verde (*Phaseolus vulgaris* L.), soya (*Glycine max* L., Mer.) y canola (*Brassica napus* L.). Se han desarrollado presupuestos empresariales para los cinco cultivos. Los presupuestos, los precios históricos y los rendimientos han sido usados como “inputs” en un sistema de simulación llamado Monte Carlo. La simulación se realizó para determinar el impacto de los cultivos de rotación

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ADDITIONAL KEY WORDS: Monte-Carlo simulation, enterprise budgets, net income

ABBREVIATIONS: ARS, Agricultural Research Service; ERS, Economic Research Service; NASS, National Agricultural Statistical Service; NEASS, New England Agricultural Statistical Service; NYASS, New York State Agricultural Statistical Service

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en las utilidades y el riesgo en los ingresos, medidos en función a la variabilidad de los ingresos. Los ingresos netos de las cinco secuencias de rotación se compararon con el cultivo continuo de papa. Dos cultivos de rotación el maíz y los frijoles dieron como resultado un aumento en el beneficio neto en comparación con el cultivo continuo de papa. Se encontró que todos los cultivos de rotación reducen enormemente el riesgo en el rendimiento y la posibilidad de pérdidas económicas. En el caso del frijol el análisis fue repetido usando datos de las pruebas experimentales de rendimiento en el cultivo siguiente de papa. Dependiendo de que el efecto de rotación fuera negativo o positivo, los ingresos netos suben o bajan en comparación al primer análisis. Si embargo, aún cuando el cultivo en rotación da como resultado rendimientos más bajos en el siguiente cultivo de papa, la variación en las ganancias y probabilidades de pérdida económica fueron superiores a la rotación continua de papa. Estos hallazgos respaldan el hecho de incluir la rotación de cultivos como un método para mejorar la producción y sostenibilidad de cultivo de papa y el incremento en las utilidades de toda la finca, reduciendo así el riesgo en los ingresos.

INTRODUCTION

Potato (*Solanum tuberosum* L.) cropping systems in Maine rely on short rotations with barley-potato as the current industry standard. There are concerns that this short rotation, as well as longer ones of continuous potatoes, may be limiting the potential productivity of the system. As shown in Figure 1, potato yields in Maine have been virtually stagnant over the past half-century. Over the same period the yields in all other fall-producing states have shown an upward trend. In 1949 Maine yields were 276 cwt/acre. In 2000, Maine had yields of 280 cwt/acre. In contrast, Idaho went from yields of slightly less than 200 cwt/acre in 1949 to yields consistently over 400 cwt/acre by the 1990s (USDA-ERS 2003).

Greater production in other regions than in Maine can be attributed to better growing conditions, a longer season and longer days, and more efficient management of moisture conditions, especially in the Northwest. However, the absence of production increases is a major concern for Maine producers because it significantly affects their competitive position. First, it can put them at a disadvantage relative to other pro-

ducing regions. If Maine's yields are 33% less than their major competitors, then production costs in Maine would need to be 33% less in order to be competitive, *ceteris paribus*. The weakening of Maine's position in potato production is illustrated by the drop in acreage since 1949. At that time, Maine grew more than 150,000 acres of potatoes. By 2002 this figure had dropped to 64,000 acres (ERS 2003). To some extent transportation costs can lessen the disadvantage, especially for processing potatoes (i.e., processing potatoes generally cannot absorb the transportation costs for large distances), and in fact a significant shift from tablestock production to processing has occurred over the last 20 years in Maine. In 2001, 67% of Maine's production went to processing, 23% to seed production, and 10% to tablestock. Of course, much of this shift was fueled by changes in demand. While this shift has helped Maine's industry survive, processing prices per hundredweight are normally significantly lower than tablestock prices.¹ Due to their higher price, tablestock potatoes can absorb higher transportation costs than potatoes used for processing. However, even in this market Maine has faced difficulties and lost market share. Initially, the loss was blamed on an inferior pack and cultivar selection. More, recently, the weak Canadian dollar has led to a large increase in Canadian potatoes in major eastern markets. For example, in Boston, shipments from Maine decreased by 50% over the period from 1990 to 1998, while arrivals from Canada increased by nearly 300% (Planning Decisions 2003). This pattern in loss of market share was similar in New York City, Baltimore, and Atlanta. These facts and the lower value of the Canadian dollar have allowed northwestern and Canadian producers to gain access to eastern U.S. markets, and Maine has found it increasingly difficult to compete.

Another major impact of stagnant productivity is the resulting "cost squeeze" placed on growers. Increased production costs can be offset if accompanied by commensurate increases in productivity. It is clear that potato production is much more capital- and other-inputs-intensive than 50 years ago. According to the National Statistical Service, the ratio of the price received index by potato and dry edible bean producers to the price paid index by producers for commodities,

¹On a national basis, over the period from 1986 to 2002 processed potato prices averaged 67% of the price received by for tablestock potatoes, varying from a high of 95% in 1996 to a low of 47% in 1989 and 2001 (NASS 2003).

services, taxes, and wages has decreased from 99% in 1991 to 81% in 2000 (NASS, 2003). Figure 1 indicates that the productivity of Maine's potato cropping systems has not kept pace with the costs of production over the same 50-year period.

The practice of short rotation sequences and the rotation crops used may offer a partial explanation for the lack of any long-term yield gains. While two year-rotations have produced yield increases in other production areas, that has not been the case in Maine. However, the short-term rotation of barley-potato or continuous potato is dictated by the economic imperatives facing growers and their lack of profitable options. Short-term rotations assure the grower that potatoes, a high-value crop, will only be out of production a brief time.

Growers in Maine recognize that there are potential long-term agronomic benefits from different rotation crops and longer rotations. Some of the potential agronomic benefits of rotation crops include improved soil physical properties, increased organic matter, improved soil fertility, more efficient use of nitrogen and water, and a disruption in disease, insect, and weed cycles. These benefits improve the overall productivity and sustainability of the target crop and the cropping system designed around it. However, growers are less sure of the long-term economic benefits of these practices. In 1997 the USDA-ARS New England Plant, Soil, and Water Laboratory (NEPSWL) conducted a grower workshop to develop a research agenda for the industry. The number one priority identified by growers was the need for profitable rotation crops.

Much work has been devoted to the impact of rotation practices on grains and forages with respect to yield gains, input use reduction, environmental quality, and economic profitability. Some representative studies include Johnson and Ali (1982), Doster et al. (1983), Helmers et al. (1986), Hesterman et al. (1986), and Christenson et al. (1995). For two thorough reviews on the economic implications of crop diversification in the Canadian prairies and northern Great Plains, refer to Zentner et al. (2002) and Entz et al. (2002), respectively. However, less attention has been directed towards the economic impact of potato cropping systems. The few studies that have examined the economic efficacy of rotation crops in potato cropping systems have had mixed results.

Rowberry and Anderson (1983) compared seven years of continuous potato (cvs Norchip and Kennebec) production to potatoes in rotation with malting barley, grain corn, and soybean with respect to profitability. Their results showed that continuous potatoes were more profitable than the rotation

sequences. However, they did note a yield decline for continuous production of Kennebec potatoes.

Lazurus and White (1984) examined the impact on farm pesticide usage of introducing rotations to a model Long Island potato farm. As part of the study they also estimated the profitability of each rotation sequence. Several rotation crops were examined including rye, field corn, winter wheat, soybean, oats, sunflower, dry bean, cauliflower, and cabbage. In their analysis, linear programming was used to model a representative farm. The objective function was to maximize returns above variable costs. No agronomic benefits of the rotation crops were examined except their impact on pesticide usage. Potato yields were assumed to be unaffected. While their results showed that pesticide usage was reduced when a rotation crop was introduced, this reduction in pesticide usage reduced the returns above variable costs. Thus, producers have a strong economic incentive to remain in continuous potato production as opposed to rotations including field crops. The two produce crops, cauliflower and cabbage, outperformed continuous potatoes in terms of returns above variable costs. However, the authors noted that producers were hesitant to adopt these crops because of increased labor needs.

Watkins and Lu (1998) measured the economic impact and environmental outcomes associated with using two-, three-, and four-year seed potato rotations in southwestern Idaho. Seed potatoes were rotated with spring wheat, feed barley, oats, and canola. Yields, nitrogen loss, and erosion were simulated using the EPIC biological simulation model. Their results showed that the most profitable and environmentally sound rotation was the three-year rotation of potatoes followed by two grain crops. Their definition of best rotation was based on a calculation of trade-offs between economic return, reduced nitrogen loss, and reduced soil erosion. From strictly an economic return criterion, annualized cash flow per hectare, a two-year rotation of potato-wheat was best. A rotation of continuous potatoes was not modeled.

Of these studies, only one (Rowberry and Anderson 1983) looked explicitly at agronomic effects of the rotation crops on the target crop. None of the studies examined the rotation crops' effect on overall system variability and productivity. Nor did any of these studies attempt to compare the cropping systems' impacts on income variability and riskiness (chance of loss).

In the following we examine the economic and agronomic impacts of including green beans, soybeans, canola, barley,

and sweet corn as rotation crops in the Maine potato cropping systems.

ECONOMIC BENEFITS OF CROP ROTATIONS

There are three sources of potential economic benefits when rotation crops are included in a cropping system. The first occurs when rotation effects either increase yields in the target crop (in this case, potatoes) at current or reduced input levels or target crop yields remain constant, but require fewer inputs. In either case, the profitability of the target crop increases. The second source of benefits arises when the rotation crop itself is profitable. For example, vegetable production is high-value and can earn a producer positive income when the acreage is not in potato production. The third source of economic benefit results from the impact of rotation crops on income variability and, therefore, on the economic risk that farmers face. The inclusion of rotation crops in a cropping system is analogous to investors diversifying their financial portfolios. Not only can rotation crops lead to a reduction in income variability, they may also lessen the likelihood of economic loss.

Heady (1952) was the first agricultural economist to make a systematic examination of the impact of crop diversification from the perspective of the impact on income variability and risk of economic losses. In his formulation, net income can be expressed as

$$(1) E(I) = (P(Y)) - C,$$

where expected income ($E(I)$) is dependent on price (P), yield (Y), and costs (C).

When only one crop is produced, income variability can be expressed as δ_i^2 , following a multivariate distribution in prices and yield, both of which are stochastic. It is assumed that costs are non-stochastic.

When a rotation crop(s) is included, income variability is defined as

$$(2) \delta_i^2 = \delta_i^2 + \delta_j^2 + 2\rho\delta_i\delta_j \text{ for } i \text{ and } j = 1 \text{ to } n,$$

where ρ is the correlation between crop i and crop j and is used to determine the covariance in income between the crops. Heady (1952) examined two cases, one in which diversification was achieved by employing more resources (perhaps by doubling the acreage) and the other where diversification was achieved by using the existing resource base (e.g., where inclusion of a rotation crop reduces the acreage devoted to the

target crop). In the first case, if a strong positive correlation exists between the net incomes of the rotation crops, income variability may increase. In the second and more common case, crop diversification can reduce income variability even when the correlation is relatively high and positive. The reason is that total income variability, when resources are fixed, expands to

$$(3) \delta_i^2 = q^2\delta_i^2 + (1-q)^2\delta_j^2 + 2\rho q(1-q)\delta_i\delta_j,$$

where q is the proportion of resources allocated to each crop. Thus, even when there is a high positive correlation, the impact is diminished.

In both resource cases, if there is not a high positive correlation between the crops, inclusion of rotation crop can reduce income variability, as reduced income from one crop is more likely to be compensated by increased income from the other crop (Heady 1952; Stovall 1966). Crop rotations can also reduce the likelihood of economic losses, as well as reduce the chances of large economic gains.

Simulation models can be used to model the economic impacts of rotation crops. These techniques can be used to estimate probability distributions for various economic enterprise combinations when sufficient agronomic data are not available (Griffin and Hesterman 1991). Using Monte Carlo simulation, numerous combinations of price and yield can be used to generate a distribution of potential net incomes based on historical price and yield series.

This research examines the potential economic impact of selected rotation crops in Maine potato cropping systems. The objectives of this research are (1) to identify the net income derived from each rotation sequence; (2) to estimate and compare each rotation sequence's effect on income variability; and (3) to estimate the likelihood of economic losses under each rotation sequence.

MATERIALS AND METHODS

The NEPSWL has conducted a long-term (four years) study of specific two-year rotation cropping systems for potato production at its Newport, Maine, site. Field plot experiments were set up as randomized complete block designs consisting of four replicate plots (24.2 x 3.7 m) for each of the six cropping systems. Two separate fields of the same two-year rotations, representing different crop entry points, were established in 1997 and 1998. Thus, potato rotation crops were grown each year. Crops used in rotation included barley

TABLE 1—*Enterprise budgets for potatoes and rotation crops in \$/acre.*

Expense	Crop					
	Potatoes	Barley	Sweet Corn	Green Beans	Soybeans	Canola
Variable Costs	1172.00	84.00	918.00	794.93	86.00	88.00
Fixed Costs	353.00	22.00	154.00	305.07	25.00	27.00
Total Costs	1525.00	106.00	1072.00	1100.00	111.00	115.00

TABLE 2—*Simple correlation coefficients between potatoes and rotation crops.*

Crops	Potatoes	
	Yield Correlations	Price Correlations
Potato	1.000	1.000
Canola	0.429	-0.385
Barley	-0.227	-0.402
Sweet Corn	0.115	0.443
Green Bean	-0.428	0.199
Soy Bean	-0.491	0.037

(*Hordeum vulgare* L.), green bean (*Phaseolus vulgaris* L.), soybean (*Glycine max* L., Mer.), canola (*Brassica napus*, L.), and sweet corn (*Zea mays*, L.). Tillage for all plots consisted of primary tillage with a chisel plow and then secondary tillage of one to two diskings prior to planting. Cut seedpieces of the potato cultivar Russet Burbank were planted by hand in each plot. The variables of interest in the crop management study included physical and chemical soil characteristics, organic carbon levels, nitrogen levels, microbial populations, disease incidence and suppression, and yield impacts on potatoes, including grade, size, and non-marketability.

Monte Carlo simulations were performed using Latin Hypercube sampling to estimate the expected mean net income and income variability for each crop and rotation sequence. In the simulation, crop yields and prices are stochastic variables with distributions defined by historical data. Six two-year rotation sequences were estimated: (1) potato-potato; (2) barley-potato; (3) sweet corn-potato; (4) green bean-potato; (5) soybean-potato; and (6) canola-potato.

Enterprise budgets reflecting Maine's conditions were developed for each crop. In the case of soybean and canola, USDA crop budgets for the northeastern USA were modified as these crops are new to Maine and the acreage is relatively small. The budgets were developed assuming a 400-acre farm, with 200 acres in each crop. A summary of the enterprise budgets is shown in Table 1. Historical data for Maine prices and yields were used whenever possible to provide the data (mean

and variance) to run the Monte Carlo simulation (NESS 2001). In the case of barley, soybeans, and canola, where public data of sufficient length for Maine was not available, New York State or national data were used (NYSSS 2001; NASS 2003). Potato prices were the marketing year average

for all potatoes in Maine. All prices were detrended using the Prices Producers Receive Index (ERS 2003).

Mean yields, mean prices, and their associated standard deviations for the period 1992 to 2000 were used for the initial setting. Correlation coefficients between the yield and price of potatoes with the yields and prices of the rotation crop were determined to construct the variance-covariance matrix for income simulation (Table 2). For example, during 1992 to 2000 canola yields and potato yields exhibited a correlation coefficient of 0.429. Over the same period their prices exhibited a correlation of -0.385. Each cropping system (or rotation sequence) was considered independently of all others, so no correlations between the rotation crops were determined.

The yield and price distributions for all crops were truncated at levels 10% below or 10% above their historical minimums and maximums to improve the model's realism. Normal distributions were assumed for both yield and price variables. Data used in the model were analyzed using the @Risk fit distribution module (Palisade 2001). In all cases, the normal distribution provided a "goodness of fit" equal or superior to any other distribution.

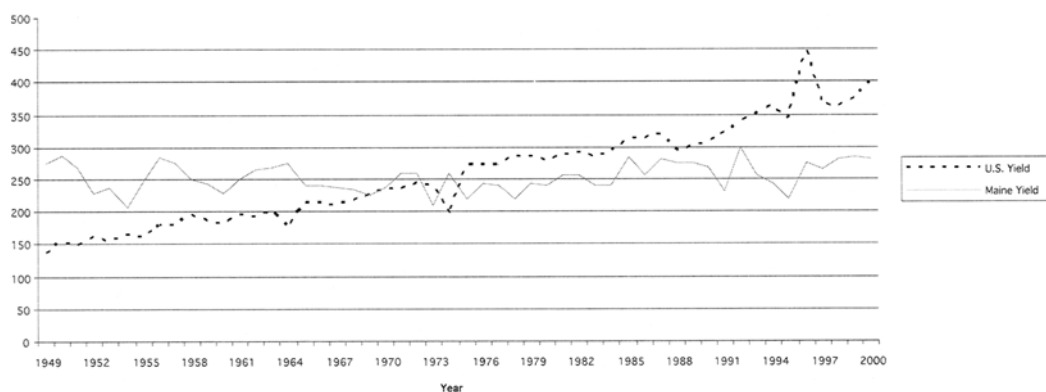
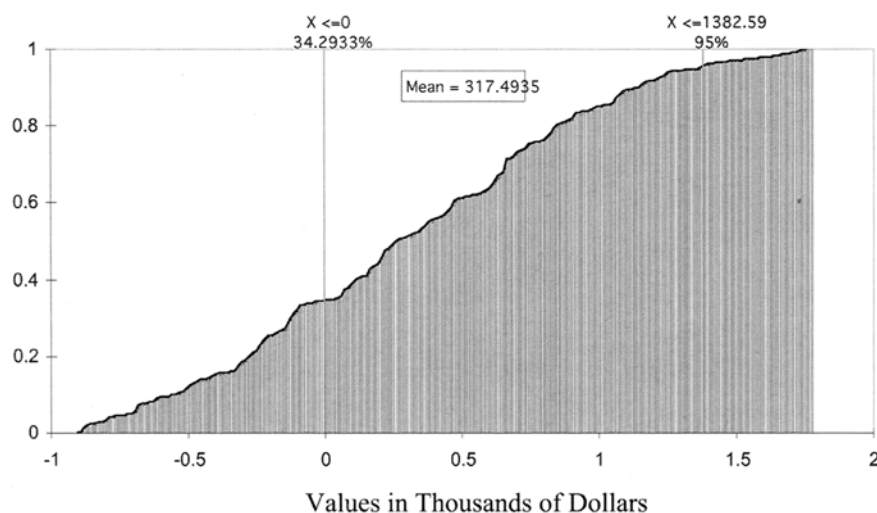
RESULTS

Experimental results showed that rotations with green beans and canola significantly affected the yield of the subsequent potato crop; however, all other rotations studied did not influence potato yield. Therefore, the simulation was run twice for the green bean and canola rotation sequences; the first assumed that there was no rotation impact on the potato crop and the second included the rotation impact as identified in the field trials. This was done to illustrate the effects of both positive and negative rotation impacts on the economic variables.

The results for the six cropping systems are summarized in Table 3. The figures represent the results per acre over the two-year span of the rotation. These results do not incorporate any

TABLE 3—Total net income distributions for potato rotation sequences.

	Potato/ Potato	Canola/ Potato	Barley/ Potato	Sweet Corn/ Potato	Green Bean/ Potato	Soybean/ Potato
	—Dollars/acre—					
Mean	317	136	130	424	1010	178
Lower CI Limit ¹	293	131	125	409	985	173
Upper CI Limit ¹	339	141	135	438	1035	182
Coefficient of Variation	2.015	1.01	1.111	0.954	0.702	0.753

¹CI = p5% confidence interval.FIGURE 1.
Maine and U.S. fall potato yields.FIGURE 2.
Cumulative distribution net income potato-potato.

rotation impact on the subsequent potato crop, either negative or positive. With respect to mean net income, the potato-potato rotation is superior to all other rotations with the exception of green beans-potato and sweet corn-potato. This is not surprising as both of these are high-valued commodities and their prices reflect the fresh market.

However, when income risk alone is considered, the ranking of the rotations changes considerably. The coefficient of variation is a measure of the relative variability of net income and on this basis, the potato-potato rotation has the largest relative risk, which is to be expected given that risks are diversified with crop rotations. Green bean-potato has the smallest income risk of all rotations evaluated.

Figure 2 shows the cumulative distribution of net income for the potato-potato rotation. When viewed from this perspective, the results indicate that approximately

one out of three times this rotation will incur economic losses. Figure 3 is a summary of all rotation sequences. As with green beans and sweet corn, all other rotations show less income risk with respect to the likelihood of incurring losses. The barley-potato rotation, the current industry standard, will return negative losses approximately one out of five times, while green bean-potato has approximately a one in 20 chance of returning a negative income.

As mentioned previously, the above analyses did not incorporate any yield impacts due to the rotation crop. Griffin (2002) pooled the data from each of the four years of available data from the experimental plots and found that the potato yields following green bean and canola did vary significantly (at the 95% level) from all other rotations. Normalizing yields on the potato-potato rotation, he found that potatoes following green beans exhibited yield declines of 10.4%. On the other hand, potato yields following canola increased by 12.6%. These results are shown in Figure 4.

Using these results, Monte Carlo simulations were rerun for these rotation sequences, adjusting the potato yields to reflect the impact of the preceding rotation crop. The results of this analysis are shown in Table 4.

When yield impacts of rotation crops are included, the net incomes of the sequences change greatly. While the green bean-potato rotation is still profitable, the decrease in potato yield leads to a large drop in net income from the rotation (Tables 3 and 4). Conversely, canola has a positive effect on potato yield, and net income from this rotation shows a corresponding increase. In addition, the

canola-potato rotation results in a reduction in income variability. Before the yield impacts were incorporated (Table 3) the green bean-potato rotation showed the least income risk. In neither case was the likelihood of economic losses greatly affected.

TABLE 4—*Total net income for potato rotations incorporating yield impact.*

	Green Bean/Potato	Canola/Potato
	Dollars/Acre	
Mean	550	268
Lower CI Limit ¹	535	263
Upper CI Limit ¹	565	273
Coefficient of Variation	0.775	0.484

¹CI = p5% confidence interval.

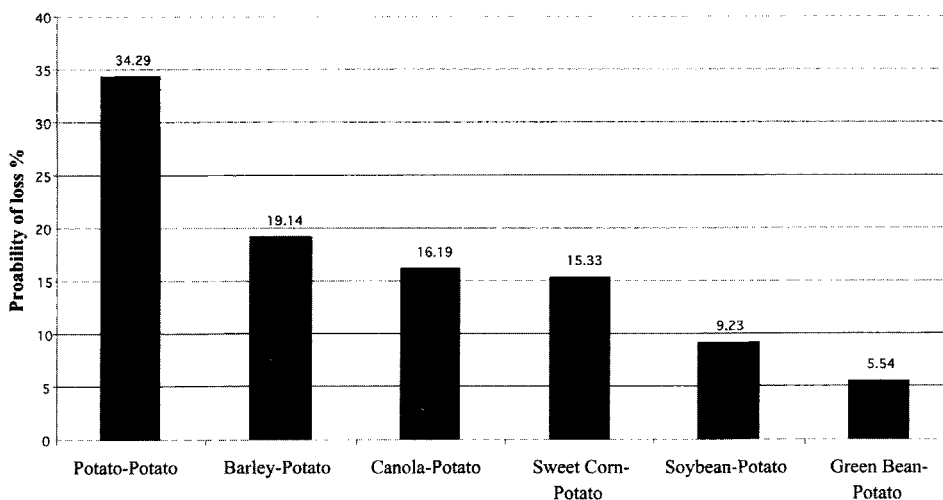


FIGURE 3.
Percentage likelihood of economic loss by rotation system.

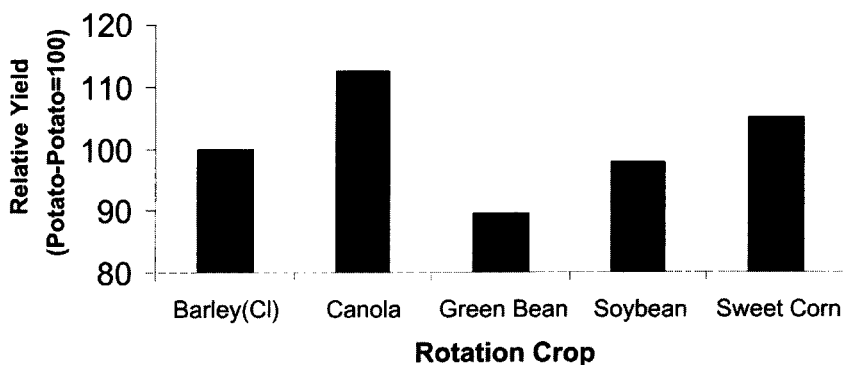


FIGURE 4.
Relative potato yields.

DISCUSSION

The results of this analysis demonstrate that modeling crop rotations can be a useful tool in establishing the potential economic benefits of rotations. Our results show that, in all cases examined, inclusion of a rotation crop decreased income variability and reduced the likelihood of economic loss when compared to continuous cropping of potatoes. For risk-averse producers, crop rotation may be an attractive strategy to reduce their overall risk. However, our analysis also shows that, with the exception of the green beans-potato and sweet corn-potato rotations, continuous potato planting outperformed all other rotations with respect to expected net income. The economic benefits resulting from green beans and corn were due to their high value as crops. Our analyses assumed that producers had market access and received the prevailing market prices for their products. Since many of these crops are grown on a limited basis, market analyses should be performed to assess the potential for increased production and likely price levels.

It is also likely that further rotation trials will more clearly delineate the rotation effects on potato yields and/or cost reduction. In this research two rotation crops did affect yield of the following potato crop, increasing the yield in one case and decreasing it in the second. These results raise the question whether, in most cases, two-year rotations are too short to see significant yield impacts on the subsequent target crop yields. They also raise the issue of whether negative rotation effects on subsequent target crops can be mitigated by a sequencing effect. For example, green beans were found to be detrimental to the subsequent potato crop (increased powdery mildew), yet they are a profitable crop. If the rotation sequence is longer, for example three years, and green beans are followed by canola, would the negative impact of green beans on potato yields be eliminated? This is one of the questions currently being addressed with ongoing research. Future analyses will incorporate the potential positive production attributes of rotation crops, such as increased soil fertility, disease suppression, or better water management, into our economic analyses. This information will further refine our evaluation of cropping system effects on total income and income variability.

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